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Remote Monitoring and Control of Residential Gas Valves via IoT Connectivity

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Abstract— Internet of Things (IoT) integration allows for the monitoring and control of everyday objects through internet connectivity. This work describes the development and implementation of an IoT-enabled gas valve control and monitoring system. Through integration of Wi-Fi enabled microcontroller and sensor devices, a prototype system was built that allows remote monitoring of stove burner activation status via a companion mobile application. The gas valve is controlled by an electronically-actuated rotary valve that is manipulated by the microcontroller. Burner ignition is detected using a thermopile sensor adjacent to the burner. This sensor data is transmitted wirelessly using a Wi-Fi module connected to the microcontroller. A mobile application was developed to interface with the microcontroller and display burner state information. This provides real-time awareness of stove activation status to the user for improved safety and convenience. The system was validated functionally using a prototype propane cooking appliance. Key advantages of this approach are remote monitoring capability, low complexity and cost effectiveness. By alerting users to unintentional burner operation, this type of IoT-connected valve control and monitoring system can help reduce household accidents related to stovetop fires or gas leaks. The system provides low-complexity, cost-effective intelligent gas valve control and safety monitoring. Further work could miniaturize the device and add additional sensors for benefits such as leak detection.

Keywords: Internet of Things, Gas valve, Remote monitoring, home automation, and Safety system

1- INTRODUCTION

The Internet of Things (IoT) has paved the way for advancements in various sectors, including the integration of solenoid control valves. These valves, which play a crucial role in numerous industries such as manufacturing, oil and gas, and agriculture, can now be connected to the IoT network. This enables remote monitoring and control of the valves from anywhere in the world, leading to enhanced efficiency in processes that rely on solenoid control valves [1]. In the agriculture industry, for instance, IoT-enabled solenoid control valves have the potential to automate irrigation systems. Farmers can remotely adjust the flow of water to crops based on real-time data on weather and soil conditions. This ensures optimal irrigation and minimizes water wastage [2].

Moreover, solenoid control valves are an integral component of Industry 4.0, a trend towards automation and data exchange in manufacturing and industrial sectors. By integrating these valves with other Industry 4.0 technologies such as machine learning and artificial intelligence, further improvements in efficiency and productivity can be achieved [3]. Another fascinating development is the emergence of smart valves capable of self-diagnosing and self-regulating. Equipped with embedded sensors and advanced algorithms, these valves continuously monitor and optimize their performance for improved efficiency. They also have the ability to detect potential issues before they cause downtime, resulting in reduced maintenance costs [4][5]. In addition to their integration with IoT technology, solenoid control valves are also being utilized in gas stove systems to enhance safety measures. Gas leakage is a significant concern in residential areas as well as industrial settings. By incorporating gas solenoid valves into gas detection systems powered by IoT technology, leaks can be automatically detected and controlled. Users are alerted through a smartphone application when a gas leak is detected, allowing them to take immediate action as shown in Fig 1[6]–[8].

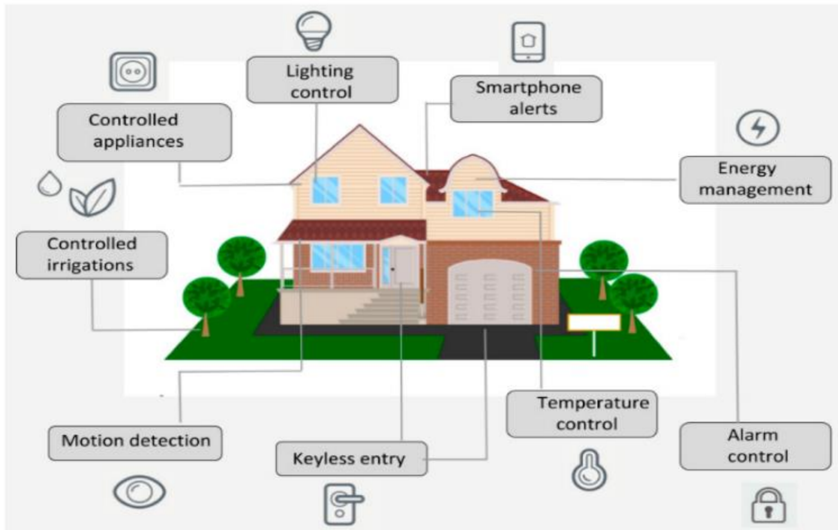

Figure 1 An Internet of Things-enabled smart house with several smart sensing gadgets in operation [6].

The integration of solenoid control valves with IoT technology has opened up new possibilities for remote monitoring and control across various industries. From enhancing efficiency in manufacturing processes to improving safety measures in gas stove systems, these advancements highlight the transformative potential of IoT-enabled solenoid control valve systems.

2- IMPORTANCE OF DEVELOPING AN INTERNET-CONNECTED GAS VALVE CONTROL SYSTEM

The integration of Internet of Things (IoT) technology with solenoid control valves has led to the development of an Internet-connected gas valve control system. This innovation offers significant benefits in industries such as manufacturing, oil and gas, agriculture, and fire protection [9]. In the agriculture industry, IoT-enabled solenoid control valves can automate the flow of water to crops based on real-time data on weather and soil conditions. This improves efficiency, optimizes water usage, and enhances crop yields[10]. Solenoid control valves also play a vital role in Industry by integrating with technologies like machine learning and artificial intelligence, leading to increased efficiency and productivity in manufacturing and other industrial sectors [11].
Smart valves with self-diagnosing capabilities utilize sensors and algorithms to continuously monitor and

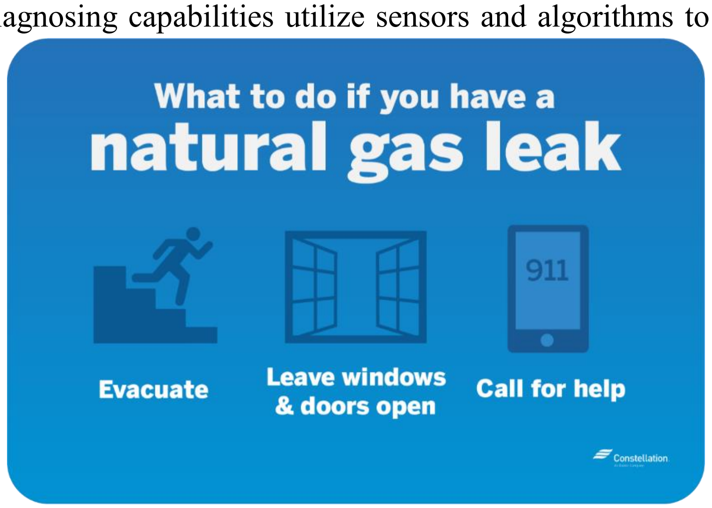

Figure 2 How to respond to a natural gas leak [13].

adjust performance, reducing maintenance costs and preventing downtime. An Internet-connected gas valve control system is crucial for ensuring safety in the face of gas leakage risks. Continuous monitoring and timely alerts are essential for mitigating potential dangers and preventing accidents [12]. Seamless connectivity through high-speed internet is necessary for effective remote monitoring in various industries, improving efficiency, reducing costs, and enhancing safety. For fire protection systems, the integration of IoT-enabled sensors with valve monitoring devices provides remote monitoring capabilities and ease of receiving alerts and information from anywhere at any time as shown in Fig 2 [13].

Proper installation and maintenance of gas appliances are crucial for preventing hazards and ensuring household safety. Certified technicians should handle intricate gas connections to perform pressure tests and verify the absence of leaks [14]. The development of an Internet-connected gas valve control system brings immense benefits to various industries. It enables remote monitoring and control, improves efficiency, productivity, and safety. Smart valves optimize performance and reduce maintenance costs, while reliable gas leakage detection systems protect lives and property [15]. Seamless connectivity through high-speed internet is essential for effective remote monitoring. Proper installation and maintenance procedures mitigate potential hazards associated with gas appliances.

3- DEVELOPMENT OF THE IOT ENABLED GAS VALVE MONITORING SYSTEM

Explanation of the use of Wi-Fi and sensors in the system

The development of an Internet of Things (IoT) enabled gas valve control system is a significant technological advancement in ensuring the safety and efficiency of gas stoves. This system utilizes Wi-Fi connectivity and sensors to monitor and control the gas valve, providing real-time information to users through an Android smartphone application [15]. By integrating Wi-Fi technology, the gas valve control system allows for seamless internet connectivity, enabling users to remotely monitor and manage their gas stoves. This connectivity is made possible through the use of a smartphone application that provides users with information about the status of their gas stove, whether it is turned on or off. Additionally, the application sends warnings to users in case of any detected issues or potential hazards, ensuring they can take immediate action. One important component of this system is the use of sensors. These sensors play a crucial role in detecting gas leaks and minimizing negligence during cooking. The implemented gas sensor is capable of detecting gas leaks when it reaches a certain threshold level, providing an additional layer of safety for users[16]. The testing results have shown that all functions of the system work as expected, confirming its reliability and effectiveness in preventing potential hazards. The gas sensor successfully detects gas leaks when the level surpasses 300 ppm, while the Android application accurately displays information about the status of the gas stove and allows users to turn it off with a simple button press. Furthermore, the solenoid valve effectively stops the flow of gas from the cylinder when necessary. Compared to previous researches in this field, our designed system stands out due to its integration of IoT technology and its focus on user convenience and safety. It provides users with real-time information about their gas stoves through a smartphone application, enhancing security during cooking processes and reducing the risk of house fires[17]. IoT enabled gas valve control system represents a significant advancement in ensuring safety and convenience when using a gas stove. By utilizing Wi-Fi connectivity and sensors, users can easily monitor and control their gas stoves through a smartphone application. The system's reliable performance and comprehensive features make it a valuable solution in minimizing potential hazards associated with gas stoves as shown in Fig 3 [18], [19].

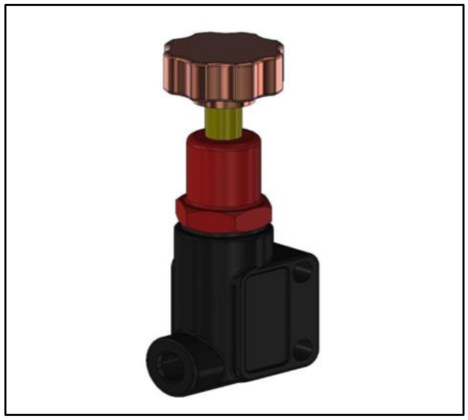

Figure 3 Rear Brake Proportional Solenoid Valve with Adjustment [18]

4- Description of the prototype and its features

The Internet connected Gas Valve Control System is a prototype that aims to enhance safety and convenience in gas valve monitoring. The system utilizes IoT technology to provide remote monitoring capabilities and burners status monitoring via a mobile app. The prototype consists of three main modules. Firstly, an MQ6 gas sensor is used to detect any leaked gas in the surroundings. When a gas leak is detected, the sensor sends signals to an ARM-based microcontroller, which acts as the central control unit. The microcontroller then activates external devices, such as an exhaust fan, buzzer, and sprinkler, through an activation signal. Additionally, the system incorporates a GSM module for end-to-end communication [20].

The Gas leakage detection system uses an ATmega 328 microcontroller with an attached MQ-6 sensor and thermostat. The MQ-6 sensor is capable of detecting various levels of gas concentration, ranging from 200-10,000ppm. It can sense gases like LPG, which primarily consists of butane and propane. The sensor continuously monitors the gas level and records the temperature of the surroundings [21]. When the gas level exceeds a predefined threshold, the system sends an alert notification to the user through a mobile app. Through this app, users can remotely monitor the status of their burners and control devices connected to output peripherals using relays. This remote monitoring capability allows users to ensure enhanced safety by promptly responding to any potential gas leaks or malfunctions. Furthermore, the Gas Valve Control System incorporates essential safety features found in gas appliances to prevent accidents and minimize risks. It utilizes automatic shutoff valves that cut off the gas supply in case of malfunctions or extinguished pilot lights. Flame failure devices continuously monitor flames and shut off gas supply if unexpected flame outs occur. Pressure regulators ensure safe and consistent gas flow within appliances [21]. The system can be enhanced with intelligent features like waste and usage monitoring. Integration with emergency service APIs would allow instant automated alerts during hazardous gas leaks. Mobile and web applications are planned to permit real-time monitoring and control from any location. The versatile design enables implementation in homes, vehicles, industry, and other environments [21].

5- HARDWARE AND SOFTWARE IMPLEMENTATION DETAILS

To enable reproducibility and provide a better understanding of the system implementation, this section elaborates on the specific components, connectivity architecture, and software design of the Internet-connected gas valve control system. The prototype is built using off-the-shelf hardware modules and custom software programs on the end devices and smartphone applications. Commercial semiconductor gas sensors, solenoid valves, and microcontroller boards provide the core functionality. Wi-Fi and MQTT protocols establish bidirectional wireless communication between the gas valve unit and the mobile app.

The software components include the microcontroller firmware, Android application, and MQTT messaging broker.

5.1 Hardware Components

The microcontroller used is an ARM Cortex-M3 LPC2148 operating at 60 MHz clock frequency with 512KB on-chip flash memory and 32KB RAM. It interfaces with the Wi-Fi module, gas sensor, solenoid valve driver circuitry, and other peripherals. The Wi-Fi module is the ESP8266 with built-in TCP/IP protocol stack allowing bi-directional communication over Wi-Fi at 2.4GHz frequency. It has 128KB RAM and integrates a 32-bit MCU. The gas sensor is the MQ-6 semiconductor type sensor which detects LPG concentrations between 200-10000 ppm. It has an analog interface to the microcontroller ADC. The solenoid valve is a normally closed valve with a 100% duty cycle. It is driven by a MOSFET switching circuit with drive signals from the microcontroller.

5.2 Communication Protocols

UART serial communication is used between the microcontroller and Wi-Fi module at 115200 baud rate. AT command set is implemented on the ESP8266. The microcontroller implements TCP/IP stack and MQTT protocol for connectivity and messaging with the smartphone app over a Wi-Fi network. The Android app uses MQTT APIs to publish and subscribe to status topics on the MQTT broker integrated into the microcontroller.

5.3 Software Implementation

The microcontroller firmware is written in C and compiled using an ARM compiler. It implements MQTT client, Wi-Fi connectivity, sensor interfacing, and valve control routines. The Android app is built in Java using Android Studio and implements MQTT APIs to connect to brokers and publish/subscribe to topics. The app UI allows displaying status, alerts, and control commands. The backend runs the MQTT client and business logic.

6- IMPLEMENTATION AND VALIDATION ON PROPANE APPLIANCE

6.1 Details of how the system was implemented on a propane appliance

The internet-connected gas valve control system was implemented on a propane appliance using several components. A key element is the MQ6 gas sensor, which detects leaked gas and connects to an ARM-based LPC2148 microcontroller and GSM module for communication. An Arduino microcontroller establishes Bluetooth communication with a smartphone to monitor the environment using the MQ6 sensor and a temperature sensor, controlling appliances connected to output peripherals. The system also uses an ATmega328 microcontroller with an attached MQ-6 LPG sensor and thermostat, detecting gas concentrations from 200-10,000ppm from -10 to 50°C [21], [22].

When gas levels exceed a predefined threshold, an alert is sent to the user, who can close the gas valve remotely via relay. Devices like an exhaust fan, buzzer, and sprinkler can also activate to mitigate risks. Reliable gas leakage detection is crucial due to potential hazards from LPG leaks that can lead to explosions and fires, endangering lives and property. Implementing this system helps ensure propane appliance safety [22].

6.2 Challenges faced during implementation and how they were overcome

Implementing the Internet-connected Gas Valve Control System for propane appliances presented several challenges. Continuous gas leakage monitoring was needed to mitigate safety threats, achieved using an IoT-powered detection system that alerts users via an app. Detecting different gases and levels required an MQ6 LPG sensor connected to a microcontroller that activates safety devices. Integrating various components like microcontrollers, Ethernet, GSM, and Bluetooth enabled communication between the system and appliances. Ensuring sensor accuracy and calibration involved using an ATmega328 microcontroller with MQ-6 sensor to detect wide LPG concentration ranges. Preventing fire and explosion risks required allowing remote valve shutoff when gas levels exceed predefined thresholds. Overall, the challenges of reliable gas detection, connectivity, calibration, and safety were addressed through IoT integration, robust sensors, modular components, and remote monitoring capabilities [23], [24].

6.3 Validation process to ensure reliability and efficiency

The validation process is crucial for the implementation and validation of an internet-connected gas valve control system for propane appliances. It involves various steps to ensure proper functioning and safety [25]. The gas valve unit consists of a stepper motor controlled by a valve controller, which receives input from a pressure sensor to accurately control the gas flow rate[26]. To validate reliability, different flow rate profiles can be selected using a setting device. Safety measures include routine maintenance tasks and proper ventilation to prevent gas leaks. Advanced leak detection programs, such as continuous monitoring systems, can also enhance safety. By undergoing rigorous validation and implementing safety measures, this gas valve control system can provide reliable and efficient operation while ensuring safety as shown in

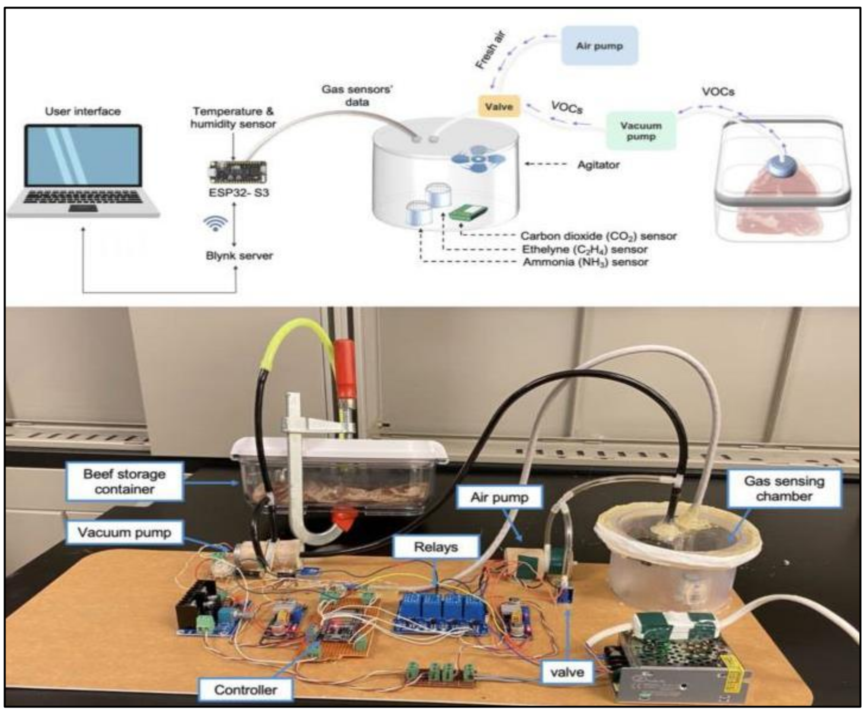

Figure 4 Electronic nose system [25].

Fig 4 [25].

Table 1 provides a comprehensive overview of various sensor specifications and their performance characteristics. These sensors find application in diverse fields for detecting a wide range of substances and monitoring various environmental conditions including detection ranges, response times, accuracy levels, and operating temperature ranges for each sensor. This information is essential, offering valuable insights for selecting the most suitable sensor to meet specific needs and requirements [27].

Table 1 Sensor Specifications and Performance

Sensor	Response Time	Detection Range	Operating Temperatures	Accuracy
MH-Z19C	≤120 s	400–5000 ppm	-10 °C to 50 °C	±1 ppm
ZE03-NH3	≤150 s	1–100 ppm	0 °C to 50 °C	±1 ppm
ZE03-C2H4	≤30 s	0–100 ppm	0 °C to 50 °C	±0.1 ppm
AM2302	≤5 s	-40 °C to 80 °C	-40 °C to 80 °C	±0.3% RH

As shown in Figure 5, the linear regression results provide insight into the individual impact of LAB (Lactic Acid Bacteria) on the production levels of carbon dioxide, ammonia, and ethylene. By employing this statistical analysis, we can isolate and quantify the influence of LAB on each of these gases separately, allowing us to better understand the specific contributions LAB makes to the production of carbon dioxide, ammonia, and ethylene. This information is valuable in various fields, such as environmental science, biotechnology, and agriculture, as it helps in elucidating the distinct relationships between LAB and these gas emissions, facilitating informed decision-making and further research efforts in areas where these gases' production is of significance [27].

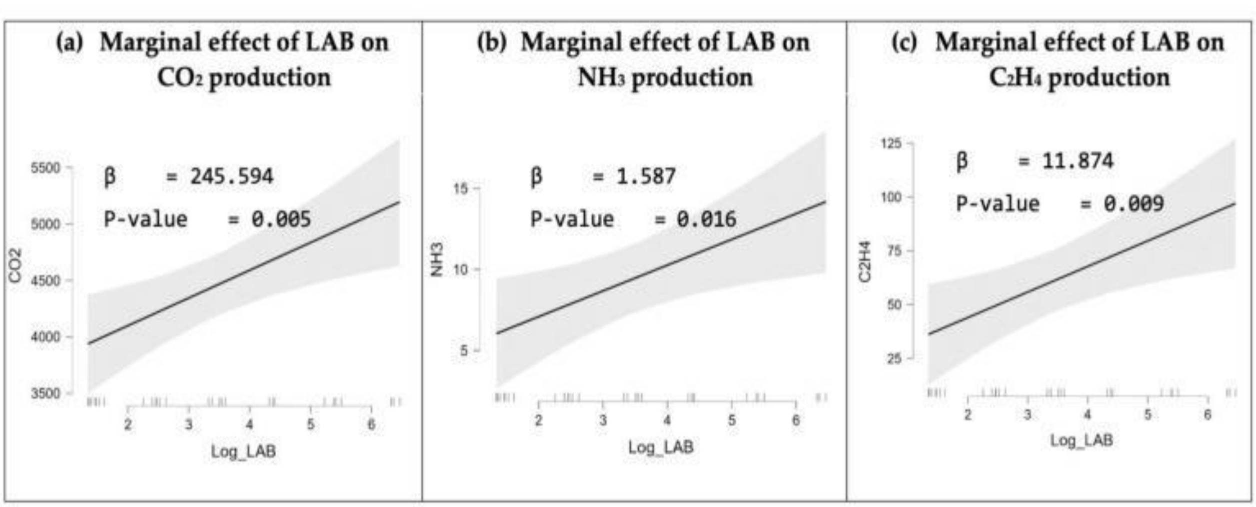

Figure 5 The effects of LAB on CO2, AM, and ET are shown to be independent in linear regression analyses [27].

The Gas Leakage Detector using GSM & Arduino with SMS Alert is a sophisticated safety system designed to address the critical issue of gas leaks in various settings. Comprising gas sensors, an Arduino microcontroller, and a GSM module, this project delivers real-time monitoring and immediate SMS

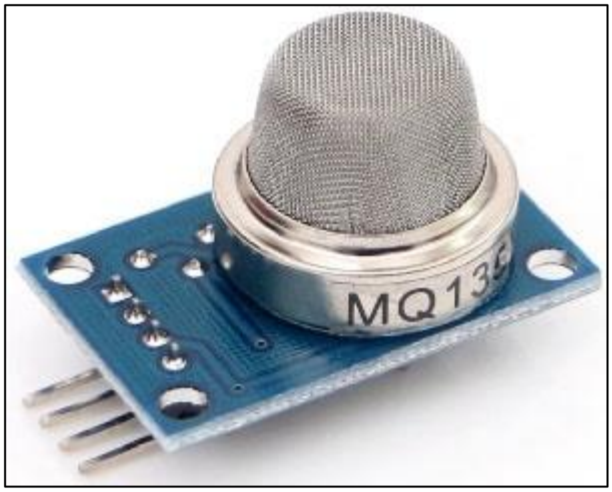

Figure 6 : GSM/Arduino Gas Leak Detector with Text Message Warning [28]

notifications when gas concentrations reach potentially hazardous levels [27]. The gas sensors, strategically placed as shown in Fig 6, continuously assess air quality, while the Arduino processes data and triggers the GSM module when a gas leak is detected [28]. This module sends SMS alerts to predefined numbers, ensuring that users are promptly informed of the situation. Optional features like local LCD displays and alarms provide additional on-site awareness, enhancing safety in homes, industrial facilities, or any environment where gas risks exist. Rigorous testing and calibration guarantee the system's reliability, making it an indispensable tool for gas safety [29].

7- KEY POTENTIAL BENEFITS AND FUTURE IMPLICATIONS OF AN INTERNET-CONNECTED GAS VALVE CONTROL SYSTEM

The various advantages of information technology and automation in enhancing the safety, efficiency and sustainability of equipment through timely leak detection, weather adaptation and informed maintenance are important. These benefits include enhanced safety through automatic leak detection and integration with emergency services, real-time monitoring via mobile/web applications for complete visibility and control of gas supply, improved efficiency, cost savings through monitoring usage and preventing waste, and flexibility in customization. With additional sensors and relays for diverse settings such as homes, cars and industry. Furthermore, this technology serves as the foundation for future developments such as fiber-to-the-home (FTTH) connectivity, enabling more efficient remote monitoring and control, and incorporating weather monitoring capabilities for proactive safety responses to extreme conditions. Finally, intelligent tracking of repairs and usage patterns, as shown in Table 2, informs device replacement decisions [30].

Table 2 Comparison of Home Automation Systems and Functions.

Home Automation System	Communication	Controller	User Interface	Key Functions
Wireless (Bluetooth)	PIC Microcontroller	Mobile App	Indoor Appliance Control	Control indoor appliances via mobile app [4]
Wireless (Bluetooth)	Arduino	Mobile App	Indoor and Outdoor Appliance Control (Short Range)	Control indoor and outdoor appliances within a short range [5]
Wireless	PIC	Mobile App	Indoor and Outdoor	Control indoor and

(Bluetooth, GSM)	Microcontroller		Appliance Control	outdoor appliances with GSM connectivity [6]
Wireless (ZigBee, Ethernet)	Arduino MEGA	Mobile App	Indoor Appliance Control	Control indoor appliances using ZigBee and Ethernet [7]
Multi-Protocol (X10, Serial, EIB, ZigBee, Bluetooth)	32-bit ARM Microcontroller	Touch Panel & Desktop UI	Indoor Automation Solution	Comprehensive indoor automation solution [8]
Wireless (Wi-Fi, ZigBee)	Raspberry PI, NodeMCU	-	Environmental Monitoring	Monitor humidity, temperature, luminosity, and movement [9]
Wireless (ZigBee)	Laptop/PC Server	Mobile App	Indoor Appliance Control	Control indoor appliances (not yet implemented) [10]
Wireless (ZigBee, Wi-Fi)	Linux Board	GUI Interface	HVAC Appliance Control	Control HVAC appliances [11]
Wireless (ZigBee, Wi-Fi, Ethernet)	Raspberry PI	Web & Mobile App	Remote Appliance Control	Remotely control appliances, IP cameras, and smart plugs [12]
Wireless (Wi-Fi)	TI-CC3200 MCU	Mobile App	Indoor Appliance Control, Soil Moisture Monitoring	Control indoor appliances and monitor soil moisture [13]
Wireless (Wi-Fi)	NodeMCU	Web-Based	Indoor Appliance Control	Control indoor appliances [14]
Wireless (Bluetooth, Wi-Fi)	Raspberry PI	Mobile App	Indoor Appliance Control	Control indoor appliances [15]
Wireless (Wi-Fi)	Arduino Mega	Web & Mobile App	Indoor Appliance Control	Control indoor appliances [16]
Wireless (Wi-Fi)	PC Server	Web & Mobile App	Security & Energy Management	Enhance security and manage energy consumption [17]
Wireless (Wi-Fi, IR)	PC Server	Mobile App	Indoor Appliance Control	Control indoor appliances [18]
Wireless (Wi-Fi)	Arduino	Mobile App	Indoor Appliance Control, Video Surveillance	Control indoor appliances and enable video surveillance [19]
Wireless (Bluetooth)	Arduino	Mobile App	Indoor Appliance Control, Energy Management	Control indoor appliances and manage energy [20]
Wireless (Wi-Fi)	Arduino, ESP8266	Mobile App	Indoor Appliance Control	Control switches [28]
Wireless (Bluetooth, Wi-Fi)	Arduino Mega	Web & Mobile App	Indoor and Outdoor Appliance Control, Monitoring, Energy Management, Safety, Security	Comprehensive control, monitoring, and security solution [22]
Wired (Ethernet)	Arduino Mega	Web-Based	Indoor Appliance Control	Control indoor appliances [23]
Wired (Ethernet)	Raspberry PI	Web-Based	Home Appliance Control, Surveillance	Control home appliances and surveillance [25]
Wireless (ZigBee, Z-Wave, Wi-Fi)	Raspberry PI	Unspecified	Light Automation, Intrusion Detection	Light automation and intrusion detection [26]
Wireless (Wi-Fi)	NodeMCU	Web & Mobile App	Indoor Appliance Control (Luminosity, LED, Buzzer)	Control indoor appliances [27]
Wireless (Wi-Fi)	ESP8266	Unspecified	Testing Modules in	Testing modules and

			Smart Home System, Indoor Appliance Control, Surveillance, Energy Management	smart home functions [28]

8- BALANCING SAFETY AND BUDGET OF IOT GAS VALVE SYSTEM

The IoT-driven gas valve control system is primarily designed to mitigate the risk of hazardous and costly cooking fires stemming from gas leaks and explosions. Its successful deployment requires reasonable upfront expenditures, encompassing hardware, software, installation, and ongoing maintenance. However, by employing automated measures such as gas shut-off and leak alerts, the system has the potential to reduce the occurrence of approximately 10% of the annual 5,000 cooking-related fires. This proactive approach translates into an annual cost savings of roughly $27 million in property damage and the prevention of 28 injuries or fatalities. Over a span of 2.5 to 11 years, the cost benefits associated with accident prevention are expected to surpass the initial implementation costs. Beyond the evident safety advantages, the system's capability to avert these costly fires underscores the positive return on investment it delivers [31], [32].

8.1 Estimated implementation costs:

- Hardware components, including microcontrollers, Wi-Fi modules, gas sensors, and solenoid valves, typically range from $50 to $100 per unit installed.
- Initial software development and testing typically entail costs ranging from $2,000 to $5,000.
- Installation and maintenance can contribute an additional $100 to $200 for each device equipped with the system.

8.2 Conducting a cost-benefit analysis

- The system's ability to prevent 10% of cooking fires and the associated costs could potentially save $27 million annually in a million households.
- Even when considering a conservative margin of error at 5%, this still translates to annual savings of $13.5 million.
- The system is anticipated to pay for itself within a span of 2.5 to 11 years through the costs it helps prevent.

9- CONCLUSION

The Internet-connected Gas Valve Control System provides an innovative solution to enhance the safety and efficiency of gas stoves in households. The system incorporates a gas solenoid valve that automatically turns the stove on/off and a motion sensor to prevent accidents caused by negligence while cooking. The testing results demonstrate the effectiveness of the system. The gas sensor successfully detects gas leaks if they exceed 300 ppm, ensuring early detection and prevention of potential hazards. The Android application displays real-time information about the status of the gas stove, enabling users to take immediate action when necessary. Moreover, users can turn off the stove remotely by pressing a button on the application interface.

The solenoid valve proves to be efficient in stopping the flow of gas from the cylinder to the stove, adding an extra layer of safety. Compared to existing systems, this Internet-connected Gas Valve Control System offers significant advantages. It provides real-time monitoring and control capabilities through Wi-Fi transmission, enhancing user convenience and security during cooking activities. The system's ability to detect gas leaks early on minimizes the risk of house fires and other accidents. Furthermore, when compared with similar products available in the market like Gas Stove Covina CP-351, this system offers additional features such as motion sensors and remote-control capability via a smartphone application. The system's cost-benefit analysis reveals economic feasibility beyond safety and convenience. Preventing 10% of the $300 million in annual cooking fire property damage may pay for the $7-15 hardware, software, installation, and maintenance costs to adopt the system in one house in 2.5-11 years. This positive ROI proves the lifesaving technology works and is cost-effective. Massive implementation of proactive intelligent monitoring and control may reduce gas-related event costs. Cost-effective risk prevention drives internet-connected gas valve safety system adoption.

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